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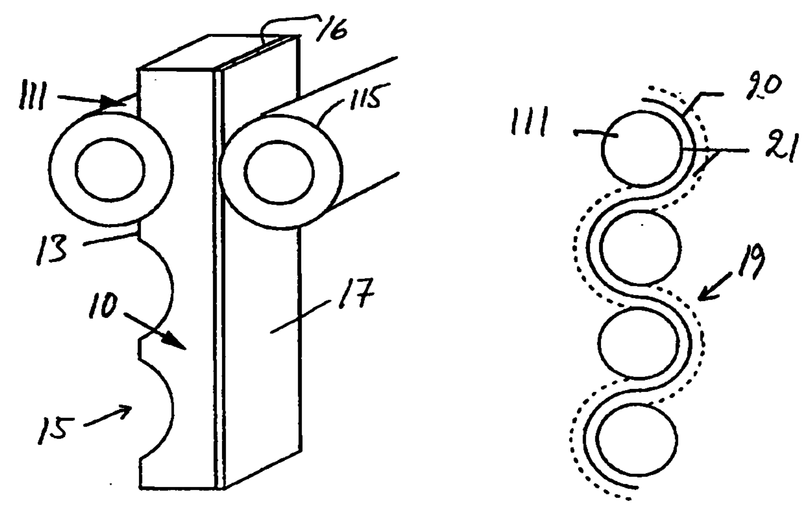

(57) Abstract

A power transformer/reactor (1) wound with high voltage cable (111) and provided with both an outer semiconducting layer (115) and spacing means in which the spacing means (4, 10, 19, 119) are arranged to separate each winding in the radial direction in order to create coaxial cylindrical cooling ducts (3), whereby at least one spacing means (4, 10, 19, 119) is electrically conducting and provided with a part (17, 21) which is resistant to wear and that the spacing means (4, 10, 19, 119), at least at one of its sides (13), is connected in a partly surrounding way to the outer semiconducting layer (115) of the high voltage cable (111).

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TRANSFORMER/REACTOR PROVIDED WITH SPACING MEANS

Technical Field

The present invention relates to an air-cooled cable wound power transformer and specially designed spacing means which form concentric cooling ducts between the cable turns.

Background of the invention

Today's power transformers are normally oil-cooled. A core is formed of a number of core legs connected by yokes and windings constituting coils (primary, secondary, regulated) which are immersed in a sealed tank filled with oil. The winding insulation consists of paper saturated with oil. Different layers of winding are separated by means of press board spacers. Press board is a form of hard pressed or laminated cellulose. The thickness of the spacers is adjusted such that the electric field between the two winding layers does not increase to such an extent that discharge takes place. Spacers made of electrically conducting material, such as metal, are never used as the electric field in the paper insulation would increase substantially. Another problem solved by the spacers is the creation of cooling ducts through which the oil may flow. The heat generated in the coil and the core is removed by oil circulating internally through the coil and the core. The circulating oil circulates outwards to an external aggregate where it is cooled. Oil circulation may either be forced by pumping oil around or it may be natural due to temperature differences in the oil. The circulating oil is cooled externally through air or water cooling devices. External air-cooling of oil may be forced or cooled through natural convection. The oil has an insulating function besides its role as a medium for heat transport in oil-cooled transformers for high voltage.

Dry transformers are normally air-cooled. They are normally cooled through natural convection as today's dry transformers are used at low power loading. Present technology is related to the following; axial cooling ducts achieved through a corrugated winding as disclosed in GB 1.147. 049, axial ducts for cooling of windings embedded in cast resin as disclosed in EP 830107410.9, the use of cross flow fans at peak load as disclosed in SE 7303919-9. The winding insulation in existing dry transformers consists as a rule of thermosetting plastics. The spacers, corresponding to oil transformers, have two functions; to sepa-

rate the winding layers suffici ntly enough from an electric point of view and to form air ducts. Electrically conducting spacers are never used for the same reason they are not used for oil transformers.

Object of the invention

The object of the invention is to achieve spacing means especially designed to enable air-cooling of a cable wound power transformer in an effective and economical way.

A further object of these spacing means is to ground an outer semiconducting layer on the cables and to support the winding turns of a transformer. A still further object of the spacing means is to function as a conductor for fault currents.

Summary of the invention

The aforementioned object is achieved in that the device, according to the invention, shows the characteristic features given in the appended claims.

The insulated conductor or cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cabl with a diam ter of 80 mm. In the present application th t rm "fl xible" is used to indicate

that the winding is flexible down to a radius f curvature in th order of four tim s the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially th same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitril rubb r (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The present invention relates to spacing means for a power transformer comprising a transformer core wound with high voltage cable. The winding is designed as concentric coils, each one of which comprises a certain number of winding turns. The spacing means are arranged to partly separate the coils in radial direction and to partly separate the winding turn of each coil in the axial direction, in order to create axial cylindrical ducts and radial disk shaped ducts.

A first embodiment of the spacing means according to the invention comprises rigid metal elements having a rectangular cross-section which are designed to be connected at the one side so as to partly surround the outer semiconducting

lay r of th high voltage cable. At the ther side, the metal elements are provided with a rubber layer which functions as a protection against abrasion of the semi-conducting layer.

According to a second embodiment of the spacing means, in accordance with the invention, these are built of an elastic metal foil on which a conducting rubber material is arranged.

According to a third embodiment of the spacing means, in accordance with the invention, the spacing means is a flexible rubber tube encircled by an electrical conducting material flexible enough to achieve a resilient pressure towards the cable and at the same time encircle the cable.

Brief description of the drawings

The invention will now be described in more detail with reference to the appended drawings.

Figure 1 shows in perspective a power transformer provided with spacing means according to the present invention.

Figure 2 shows a section through a high voltage cable according to the present invention.

Figure 3 shows a spacing means, according to the invention, located between two concentric windings.

Figure 4 shows a spacing means in detail according to a first embodiment of the invention.

Figure 5 shows a spacing means according to a second embodiment of the invention.

Figure 6 shows a spacing means according to a third embodiment of the invention

Description of the invention

Figure 1 shows a power transformer 1 provided with three winding units 2 each of which being provided with a plurality of concentrically located windings each of which being provided with a plurality of winding turns, whereby the windings form axially concentric cooling ducts 3 as the windings are radially separated by axial spacing m ans 4. The transform r, furth rmore, is conventionally provided with an iron core 5.

Figure 2 shows a cross-sectional vi w of a high voltage cable 111 to be used as a transformer winding according to the present invention. The high voltage cable 111 comprises a plurality of strands 112 having a circular cross-section of for example copper (Cu). These strands 112 are arranged in the centre of the high voltage cable 111. Around the strands 112 there is arranged a first semiconducting layer 113. Around the first semiconducting layer 113 there is arranged an insulating layer 114, of for example XLPE- insulation. Around the insulation layer 114 there is arranged a second semiconducting layer 115. The concept of a high voltage cable in the present application does thus not comprise the outer shielding screen which normally surrounds such a cable for power distribution. The high voltage cable has a diameter in the interval 20 - 200 mm and a conductor area in the interval 80 - 3000 mm^2. In the figure the three layers are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property is maintained during the entire life of the cable.

The transformer winding comprises thus high voltage cable 111 wound around the iron core whereby the transformer winding constitutes concentric windings, each one of which having a plurality of winding turns, between which windings spacing means are fitted into in order to produce concentric cooling ducts.

Figure 3 shows a rigid spacing means 10 fitted in between two concentric winding turns 11,12 of the high voltage cable 111. From the Figure it is evident that the spacing means 10 takes on the shape of the cable turn on the one side while the other side is level. Furthermore, it is evident from the figure that there is an air gap 6 between each winding turn of the high voltage cable 111.

The spacing means are displayed more clearly in Figure 4. The rigid spacing means 10 is designed with a rectangular cross-section having on its first side 13 craters in the form of cylindrical grooves 15 in which the high voltage cable 111 is designed to fit in. The spacing means 10 thus partly surrounds the outer semiconducting layer 115 of the cable. The other side 16 of the spacing means 10 is entirely level on the outside on which a rubber layer 17 is attached. The rubber layer is designed to be resistant to wear so that damages are avoided to the outer semiconducting layer 115 of the high voltage cable 111. In order to achieve grounding of the outer s miconducting layer 115, th first side 13 of th spacing means is lectrically conducting, made of for example aluminum. In such a design

the spacing m ans becom lectrically conducting on the on side and insulating against the adjacent winding on the other side.

An alternative to this embodiment is that the rubber layer is manufactured as semiconducting, whereby the rubber layer may be applied to both sides of the spacing means and in this way maintain grounding on both sides of the cable.

By letting the grooves in the spacing means be located at a distance which is larger than the diameter of the cable, an air gap is obtained between each winding turn. This air gap prevents wear from taking place between the adjacent cables.

Due to this resistance, against torsional strain and bending, of the spacing means a support system of the cables is obtained by the cables being stretched in the radial direction and by the spacing means taking up a considerable part of the weight of the coils of the cable.

Figure 5 shows a second embodiment of the present invention in which the high voltage cables 111 are separated from each other, referring to both the concentrically placed windings and each winding turn respectively, by a spacing means 19 being threaded in a meandering way between each winding turn in one and the same winding whereby the cables are separated both in the axial and in the radial direction. It is also hereby possible that the spacing means is threaded between every second turn in the winding. The spacing means is designed having a centrally located metal foil 20 which is surrounded at both its sides by a conducting rubber layer 21 which acts as a part resistant to wear. The spacing means alternately surrounds the outer semiconducting layer 115 of the cable at the one side of each of the winding turns at an angle exceeding 180°.

Furthermore, the rubber layer functions in this embodiment as a part of the spacing means which is resistant to wear and also as an electrically conducting part transmitting electric currents to the metal tape 20 from where the electric currents are led further to ground. The spacing means functions also in this case as a faulty current ground lead.

Figure 6 shows a third embodiment of the present invention in which the high voltage cables 111 are separated radially from each other by a grounding and spacing means 119. In order to establish a low ohmic spacing of the cables 111 it is important that the spacing member 119 abouts against th cables 111

with a resilient pressure and a contact surface large enough to establish a good contact between the cables and the spacing member 119. In this third preferred embodiment of the invention the said spacing is established by covering a flexible silicon rubber tube 121 with a metallic net 120 or a hollow metallic braid, see figure 6. Left in the figure the mounted spacing flexible tubes 121 as spacing means 119 are shown. The pressure from the surrounding cables 111 in the transformer winding is compressing the flexible tubes 121 so that a sufficiently high level of contact pressure is reached at the same time as the spacing flexible tube 121 is compressed and at the same time partly surrounds the cable 111. As can be seen from the figure, the spacing means 119 is surrounded by an electrical conducting material flexible enough to achieve a resilient pressure towards the cable and at the same time surround the cable.

CLAIMS

1. A power transformer/reactor, **characterized** in that it is wound with high voltage cable (111) and provided with both an outer semiconducting layer (115) and spacing means in which the spacing means (4, 10, 19, 119) are arranged to separate each winding in the radial direction in order to create coaxial cylindrical cooling ducts (3) and that at least one spacing means (4, 10, 19, 119) is electrically conducting and provided with a part (17, 21) which is resistant to wear and that the spacing means (4, 10, 19, 119), at least at one of its sides (13) is connected in a partly surrounding way to the outer semiconducting layer (115) of the high voltage cable (111).

2. A power transformer/reactor according to claim 1, **characterized** in that the one side (13) of the spacing means (10) is arranged to both be connected to the semiconducting layer (115) and be electrically conducting.

3. A power transformer/reactor according to claim 2, **characterized** in that the spacing means (10) is provided with cylindrically formed grooves (15) in which the high voltage cable (111) is designed to fit in.

4. A power transformer/reactor according to claim 3, **characterized** in that the space between the cylindrically formed grooves (15) is large enough to form an air gap (6) between each winding turn.

5. A power transformer/reactor according to any one of claims 2-4, **characterized** in that the opposite side (16) of the spacing means (10) is provided with the part (17) which is resistant to wear.

6. A power transformer /reactor according to claim 5, **characterized** in that the part (17) which is resistant to wear is manufactured of a rubber material which is levelly attached to the outer semiconducting layer (115) of the high voltage cable (111).

7. A power transformer/reactor according to claim 1, **characterized** in that the spacing means (19) is provided with a rigid electric conductor (20) which is surrounded on both sides with an electrically conducting rubber layer (21) which is resistant to wear.

8. A power transformer/reactor according to claim 7, **characterized** in that the spacing means (19) is elastic and arranged to be inserted in a meandering way between the winding turns in one and the same winding.

9. A power transformer/reactor according to claim 8, **characterized** in that the spacing means (19) is inserted between each cable turn.

10. A power transformer/reactor according to claim 9, **characterized** in that the spacing means (19) is connected alternately at its one side respectively the other side, partly surrounding the outer semiconducting layer (115) of the high voltage cable (111).

11. A power transformer /reactor according to claim 10, **characterized** in that the winding angle of the spacing means (19) exceeds 180°.

12. A power transformer/reactor according to claim 1, **characterized** in that the spacing means (119) is surrounded by an electrical conducting material flexible enough to achieve a resilient pressure towards the cable (111) and at the same time surround the cable (111).

13. A power transformer/reactor according to claim 12, **characterized** in that the spacing means (119) is a flexible rubber tube (121).

14. A power transformer/reactor according to claim 13, **characterized** in that the electrical conducting material is a metallic net (120) or a hollow metallic braid.

15. A power transformer/reactor according to any one of claims 1-14, **characterized** in that the high voltage cable (111) comprises a conductor composed of one or more strand parts (112) arranged in the centre of the high voltage cable (111), around the strand parts (112) there is arranged a first semiconducting layer (113), around the first semiconducting layer (113) there is arranged an insulating layer (114) and around the insulation layer (114) there is arranged a second semiconducting layer (115).

16. A power transformer/reactor according to claim 15, **characterized** in that said layers (113,114,115) are arranged to adhere to one another even when the insulated conductor or cable is bent.

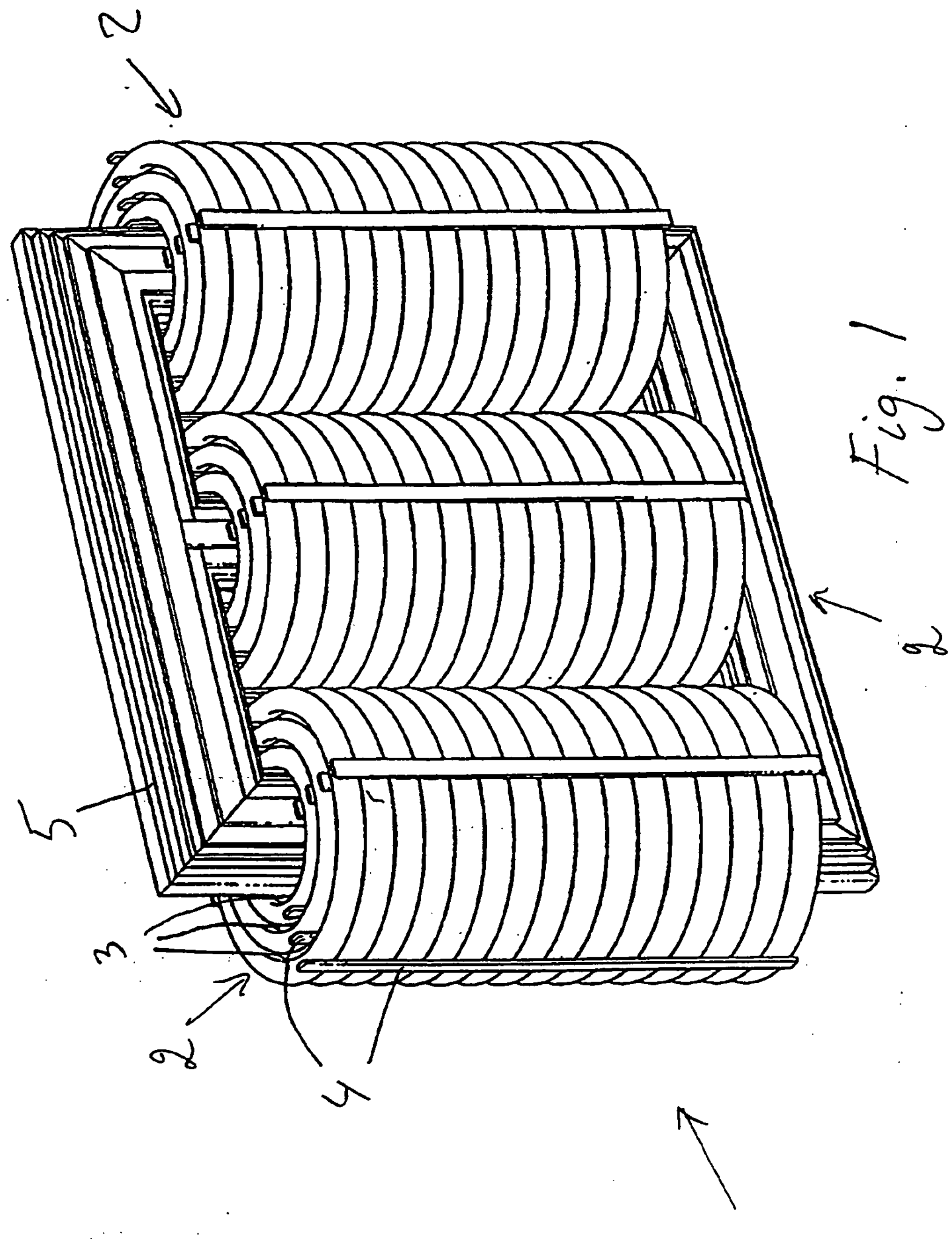

Fig. 1

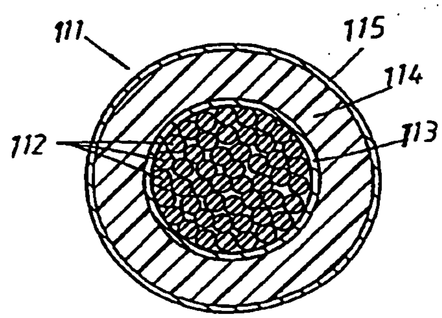

Fig. 2

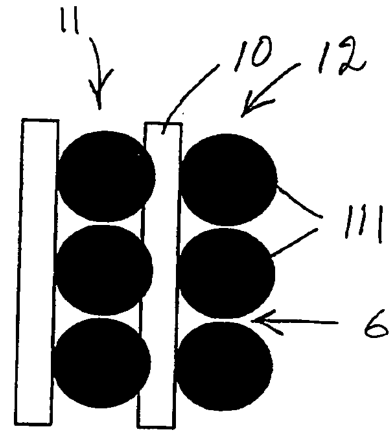

Fig. 3

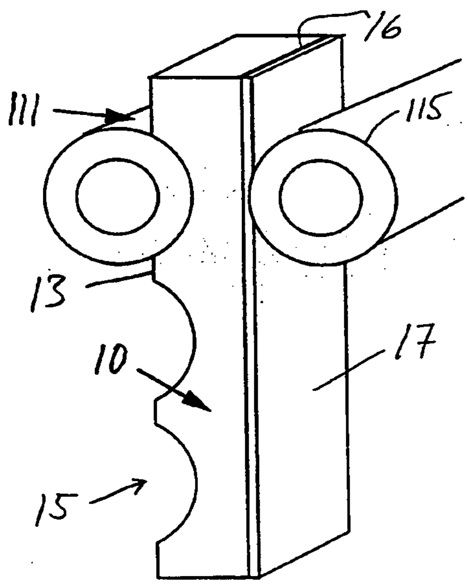

Fig. 4

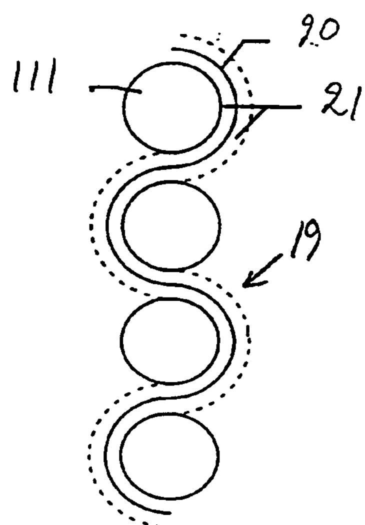

Fig. 5

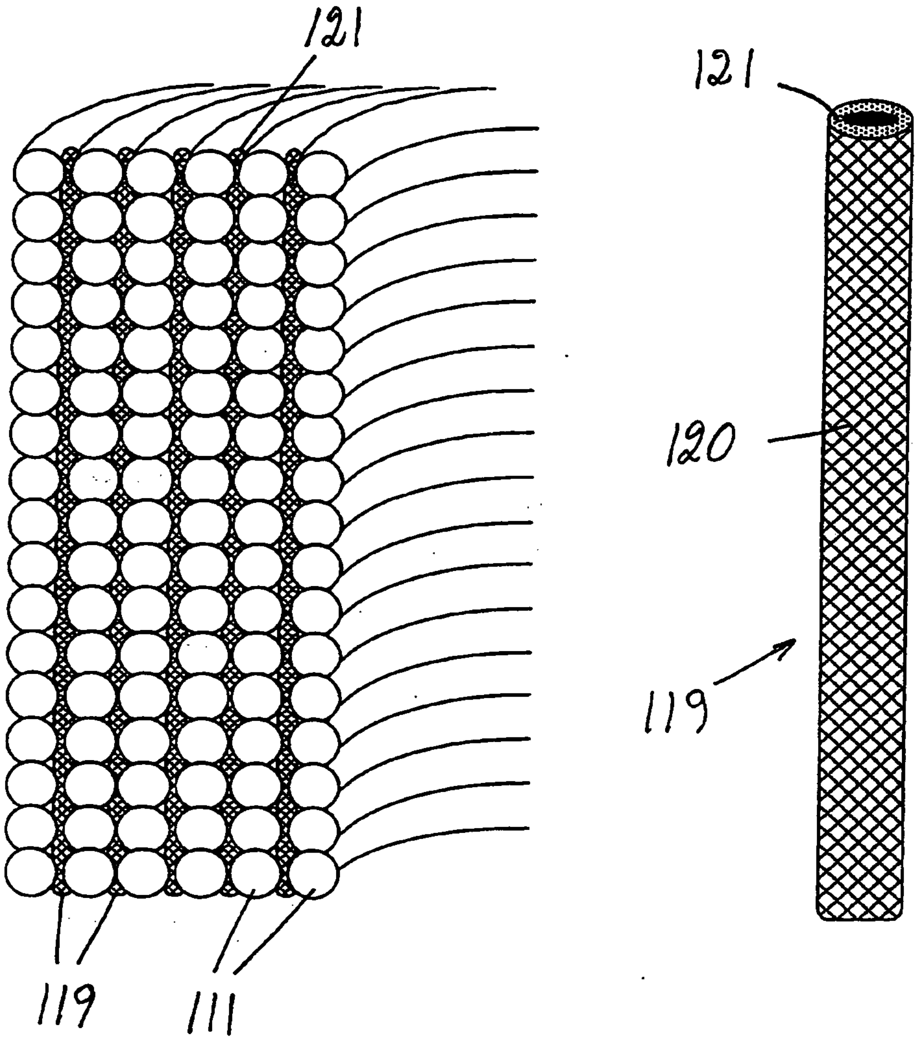

Fig 6